# Indigenous Language Revitalization using Virtual Reality

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Submitted under the supervision of Daniel Keefe to the University Honors Program at the University of Minnesota-Twin Cities in partial fulfillment of the requirements for the Bachelor of Arts, *summa cum laude* in Computer Science

Special thanks to: Dr. Daniel Keefe, Dr. Vicente Diaz, Dr. Jim Rock, Sean Dorr, Anang Hermes

May 12, 2021

**Abstract**

Working within the framework of the Indigenous Futures project, a collaborative research project between the University of Minnesota and three local Indigenous communities, this thesis explores the potential of using VR environments to facilitate Indigenous language revitalization and trans-Indigenous exchange, specifically on the topic of star knowledge and stories. I implemented a virtual night sky filled with Micronesian, Ojibwe and Dakota constellations. These constellations carry rich cultural histories, and their stories have been passed down through generations within each community, making them an ideal topic for trans-Indigenous exchange. 3D text can be incorporated into the environment to label the constellations directly in the virtual sky; however, this raises the question of how the constellations' written names should be represented. To understand this important design choice, I developed a series of visual prototypes, both in English and the respective Indigenous languages incorporating various scripts and symbols to depict each name. The prototypes also explore where and when to display these labels (i.e., side-by-side, overlapping, changing over time). In this way, the project serves as a case study of some of the many options available to Indigenous communities for representing written forms of language in VR. Early feedback from collaborating Indigenous scholars supports the potential of VR environments in this style to open the door to further conversations about the importance of language in Indigenous culture and suggests that using "morphable 3D labels" (those that change over time to depict multiple names for the same constellation) may provide a useful graphical tool for facilitating these conversations.

## 1 Introduction

The Indigenous Futures project is a joint research project between the University of Minnesota and three local Indigenous communities: the Lower Sioux, Upper Sioux, and a community of climate and economic refugees from Micronesia now living in rural Milan, MN. One aim of this project is to create a virtual reality (VR) environment for revitalizing cultural traditions and ecological knowledge that are difficult to teach without experiencing, and, as such, are particularly difficult for displaced communities to pass on from one generation to the next. For example, the first component of the VR environment developed in

the research was a simulation of sailing a traditional Micronesian outrigger canoe in Chuuk Lagoon where users can practice Paafu, a traditional water navigation technique of the Micronesian people. The night sky is depicted, including the Micronesian constellations, frequently used for navigation purposes. The local Dakota communities participating in the project also have strong water and sky traditions, and a major goal of the larger project is trans-Indigenous exchange. Thus, the team is now expanding this environment to include complementary content from the Dakota (and possibly other local Indignenous groups) traditions. My honors project combines this motivation with my specific interests in combining language and computing to explore the possibilities for how constellations and the languages used to describe them might be represented in this immersive graphical environment for trans-Indigenous exchange.

*1.1 Specific Contributions*

My specific technical contributions to this project are twofold. First, I created digital Ojibwe and D/Lakota constellation maps to complement the existing digital Micronesian constellation map. This is significant for the Indigenous Futures project because, for the first time, the project's software now explicitly depicts Traditional Ecological Knowledge from each of the partnering Indigenous communities. All of the resulting constellations may be overlaid on the virtual sky. Second, I researched and developed a variety of possible graphical methods to represent the names of (or other language associated with) the constellations. Although including 3D text in VR environments is now commonplace, this work is significant because Indigenous languages and writing systems have complex histories, deeply intertwined with colonialism. Also, many of the stories associated with the stars are passed on in the oral tradition. These make the decision of which character set(s), font(s), symbol(s), and even name(s) to use for a given constellation important and complex. In contrast to a VR language education tool designed to teach Spanish to English speakers, where the goal might be to visually represent the one correct translation for a given 3D object, here, the goal is more complex and may include conveying multiple truths, translations, and histories. VR software developers, and computer scientists in general, have developed standards

around the use of text (e.g., the Unicode standard discussed in later sections), but we do not yet have good design guidelines for how to represent language in a revitalization context like this. Beyond these two technical contributions, the thesis also reports on early feedback from interdisciplinary scholars on the Indigenous Futures research team.

### *1.2 Research Partners*

As mentioned earlier, this computing research was conducted within the context of the larger Indigneous Futures project. The ongoing pandemic has limited access to direct feedback from the communities participating in the project; something we had hoped to be able to include in this thesis. However, my thesis readers (Dr. Vince Diaz and Dr. Jim Rock) have kinship and long-standing research ties with the communities and have been close collaborators in the work. Some of their early feedback is included in the thesis. The research has also been guided throughout via bi-weekly meetings with the CS Indigenous Futures team, consisting of my advisor and two Indigenous PhD students working on the project. We believe this context is important to note before proceeding because we believe this type of research must be conducted in collaboration *with* Indigenous communities and, when possible, led *by* Indigenous communities and scholars. We are grateful to be included.

### *1.3 Indigenous Data Sovereignty*

The research also takes place in the context of a digital age that has brought forth a vast expansion of available information and data, and this has important consequences for software development, when we consider questions such as: How much information about specific groups is actually represented? With so many sources of information, how can we be sure that the information we are receiving is accurate and factual? What decisions are made based on this information? Who has the power to author or edit this information?

It is well known that Indigenous communities face special challenges in this context. One example in this specific project relates to how languages are represented with computers. I found that many of the Indigenous characters and symbols needed for the prototypes I developed fall outside of the characters available to computer programmers via the Unicode standard. As programmers and technologists, our initial reaction to this may be, "no problem, the standard is built to be extensible; we can just extend it", and this may, in fact, be a useful future direction. However, this would also have consequences that need to be considered. Today, digital representation, whether in the form of inclusion in a standard, an online web presence, Wikipedia article, census data, etc. is crucial. These data even form the basis for the "ground truth" used in many machine learning and AI decision making tools. So, from the standpoint of education and being represented in this "truth", it would seem natural to always place information online, where it can be distributed to a larger audience. However, when considered through data sovereignty, there may be a conflict. Much of this information has remained private to tribes for centuries; why should it be made available to everyone *now*? Who will benefit from this? Who will own or curate it? How will it be used in the future? Which version of the information is the "official" or "standard" version? Clearly, such questions are for the Indigenous communities to decide.

## 2 Related Work

### *2.1 Digital Environments for Indigenous Cultural Revitalization*

This work builds upon a growing area of research and projects on Indignenous data visualization, which have explored issues such as Indigenous rights concerning land (Landmark, Wily et al) and bridging the gap between the digital age and elders using 3D game engines (Rodil et al, Pumpa et al, Wyeld et al). Since the graphics environment is 3D and interactive, the work also relates to Indigenous Computer Games, such as Indigenous games like Honour Water or Spirits of Spring, both of which are children's iPad games (CBC). Additionally, video games such as He Ao Hou (2017) and Wao Kanaka: Realm of the People (2018), were designed so that the player can play in ʻŌlelo Hawaiʻi as well as in English (IGF, 2020). Finally, given our specific emphasis on star knowledge, the work is also closely related to the open

source Stellarium astronomy software (Stellarium), which includes constellation maps for multiple cultures, but does not include the more holistic approach to labeling constellations that we explore in this project.

### *2.2 Representing Languages in Computers*

Currently, the most flexible approach to graphically representing languages in computer software is by adhering to the Unicode standard. If the script is not already included in the standard, it is possible to create a new Unicode encoding for the script. Although many scripts are not present in the standard, it continues to grow, and many Indigenous languages are included.. In the past year alone, the Unicode Technical Committee has introduced 5930 characters to its standard (UTC, 2020), many of which are from new script proposals, for languages like the Nzebi languages, a collection of Bantu languages found in western Congo and Gabon (Ethnologue, 2020). To work with an Indigenous script as we are accustomed to doing in a text editor, like Microsoft Word, extending the Unicode standard is really the only option. However, since our platform supports rendering raster graphics in 3D via texture mapping, we can get around this technological limitation by creating the labels needed in an image editing program and importing these into the 3D graphics engine.

## 3 Methodology and Technical Contributions

This section describes the technical and design work behind the two main technical contributions of the thesis: Adding Digital Ojibwe and D/L/Nakota Constellation Maps, Designing the Visual Representation for Language.

### *3.1 Adding Digital Ojibwe and D/L/Nakota Constellation Maps*

Our virtual environment is implemented in Unity VR. Unity VR is the most widely used platform for virtual reality, augmented reality, and mixed reality applications (Unity Technologies, 2020). Unity is highly optimized and pipelined, which allows for smooth graphical rendering and robust structure for any

project. Our virtual reality program is an interactive, constellation map. The user can look upwards, towards the sky, and see the various constellations drawn out in the sky to scale. Users have the ability to cycle through various star maps; Ojibwe, D/L/Nakota, and Micronesian communities all have various constellation maps for the stars of the northern (and southern) night skies. Micronesian communities historically have used the stars for navigation by sea, aboard outrigger canoes. While the Ojibwe and D/L/Nakota communities historically have not *sailed* according to the stars, they *have* taught the stories of the constellations to their children and children's children. Additionally, these communities use star charts for land navigation, frequently using Polaris (or the North Star) as a beacon.

In order to properly display these constellations for each community in the Unity VR system, I first analyzed star maps for both Ojibwe and D/Lakota constellations created by Native Skywatchers, an initiative which seeks to remember and revitalize Indigenous star and earth knowledge (Native Skywatchers, 2020). Then, I created a CSV file for each constellation map, where I listed the name of the constellation, what Greek/Latin constellations it overlaps with (to facilitate looking up star IDs in online catalogs), the season it is found in, and most importantly, the individual stars that make up each constellation. The stars are represented by their Bright Star Catalogue (BSC) number, and these star numbers are read from the BSC database and placed appropriately in the sky, since each BSC number in the table has a designated position in our program's night sky.

*3.2 Designing the Visual Representation of Language*

Figure 1: Potential representation of Ojibwe constellation "Curly Tail"

*English:*

*English double vowel:*

*Canadian Aboriginal Syllabics:*

*Great Lakes Algonquian Syllabics:*

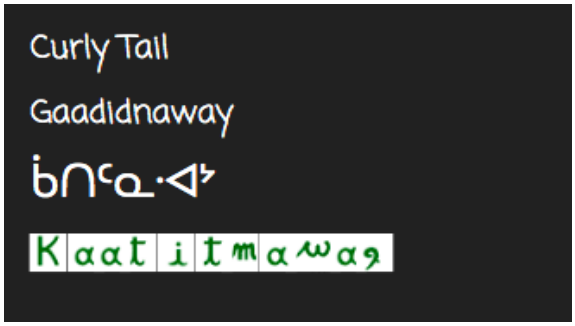


Figure 2: Potential representation of D/L/Nakota constellation “Thunderbird”

*English:*

*English adapted:*

*Curley’s alphabet:*


One of the most important design considerations for the constellation portion of this virtual reality experience is the representation of the language itself. Many Indigenous languages don’t use any sort of writing system; the languages remain primarily spoken. However, in a visual simulation, it can be useful to have some sort of *visual* representation of the language; in this case, the constellation names are placed in the night sky. In addition to the already existing Micronesian and Western constellation data, I compiled data for both Ojibwe and D/L/Nakota constellation charts. Ojibwe has a handful of written representations, the most common being the double-vowel system, which uses English letters and longer vowels to approximate Ojibwe phonology. There are other writing systems used in Ojibwe as well; Canadian Aboriginal Syllabics (CAS) is a family of abugidas used to write various Indigenous North American languages of the Algonquian, Inuit, and Athabaskan language families (Meuers, 2012). While primarily used in Canada, CAS has been adapted for Ojibwe, and this writing system is specifically used among some Ojibwe speakers in North Dakota, Minnesota, and Ontario (Omniglot). Additionally, in the mid-19th century, Great Lakes Algonquian Syllabics was created in a similar fashion; it is a collection of syllabic sounds used for various Indigenous groups of the Midwest, specifically, Ojibwe, Fox, Potowonami, Ho-Chunk, Sac, Kickapoo, and Chippewa, or Southern Ojibwe communities (Zui, 2020). Figure 1 shows an example translation of the "Curly Tail" constellation name for both of these writing systems. Both of these writing systems were created by European linguists and introduced to Indigenous leaders (Omniglot).

In D/L/Nakota, we also observe a variety of writing systems. For example, D/L/Nakota is commonly transliterated into the English alphabet, but makes use of accents and nasal markings, to better approximate D/L/Nakota phonology. However, there is another writing system used among some D/L/Nakota speakers; in 1982, Leroy Curley introduced a 41 symbol alphabet to be used in D/L/Nakota languages (IAIM, 2014). We observe the use of this alphabet in Figure 2. This alphabet is different from a syllabic inventory, since *individual phonemes* are represented by a symbol, *not* an entire syllable. The symbols are all primarily circle-based, with variations of line placement and orientation in order to distinguish sounds. Additionally, Curley re-introduced a variation of the number system used in D/L/Nakota, with numbers from 1 to 10; also circle-based symbols. This alphabet allows for a more accurate representation of true D/L/Nakota sounds, since the characters are not forced to fit within English phonology.

### *3.2.1 Colonialist History and Implications for Design*

As mentioned briefly above, it is important to note that many Indigenous writing systems were *not* created by Indigenous people, one exception being Curley's 41 character alphabet for D/L/Nakota. For example, Canadian Aboriginal Syllabics was created by James Evan, who was an English-Canadian linguist and Methodist missionary (Omniglot). While the true origins of the Great Lakes Algonquian Syllabary are unknown, it appears that there is significant French influence on the system; most likely from Canada, where French was a primary language at the time. It is possible that a non-Indigenous person created this script and taught it to local Indigenous groups, perhaps under a similar pretense as scripts before its time; Christian missions, Americanization techniques, etc (Zui, 2020). Contemporary use and teaching of Indigenous writing systems varies., in the northern territories of Canada, many road signs and public institutions make use of Canadian Aboriginal Syllabics, adapted for various Inuit languages (Weber, 2016). Many territorial governments have adopted Canadian Aboriginal Syllabics as a co-official script as well. On the other hand, members of our research team who are fluent speakers of these languages have

never encountered some of the scripts in actual use. Ideally, the visual representation of language should somehow reflect this complex history.

### *3.2.2 Graphical Prototyping*

There are many possibilities for how the scripts might be used in the virtual environment to represent the constellation names. For example, we could list just one name in English text, or two names next to each other; English and double-vowel Ojibwe, or we could overlay the names or fade between them. Additionally, we must consider whether there is a significant benefit to adding Canadian Aboriginal Syllabics or Great Lakes Algonquian Syllabics to the representation.

I followed an iterative design prototyping methodology to explore these questions. First, during bi-weekly meetings with the CS Indigenous Futures team, we discussed the various scripts I researched and brainstormed possible visual representations in the software. Then, I created a series of design prototypes to capture the possible options for graphical presentation. Using the syllabic chart from Omniglot and Curley's alphabet courtesy of IAIM, I transcribed the Indigenous names for each constellation in English, English-adapted, and a symbol based system (Figures 1 and 2 show representative examples of these transcriptions). I then implemented three types of text for each Ojibwe constellation name: the English translation of the name, the Ojibwe name written in the double-vowel writing system, and the Ojibwe name written in Canadian Aborignal Syllabics. For Dakota constellations, I include the English translation, the D/L/Nakota name in English orthography, and the Dakota name written in Curley's alphabet. Using Google Slides, I was able to create image transitions that fade in and out in sequence for each name representation. The text was white and placed on a dark gray background, very similar to how text would appear on the Unity sky map (Figures 1 and 2). This approximated the aesthetic that would be present in a Unity representation of the constellation names, and provided a useful prototype for review. Finally, I presented these for feedback in an interdisciplinary critique session held during a team design

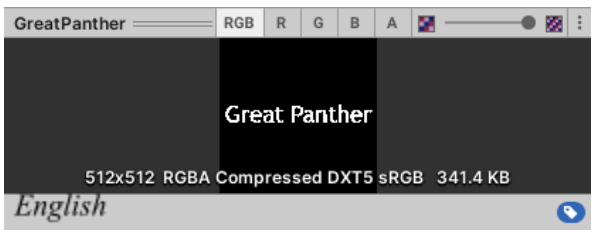
meeting. The next section shows images of the prototyping results I developed and reports on feedback from the critique session.

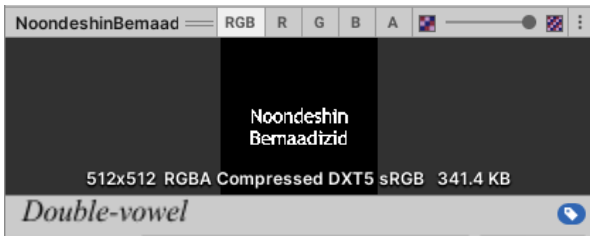
## 4 Results and Feedback

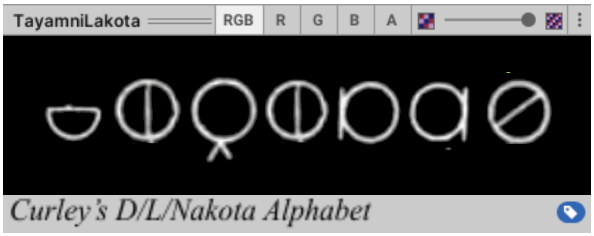
### *4.1 Graphics and Prototyping Results*

Below are the results of my representation of both Ojibwe and Dakota star and constellation names in the virtual sky within the application. For each constellation, the three names will fade in and out between each other, symbolizing the changing legacy of the language throughout time. My intent was for the three (or potentially more, when considering alternative names for constellations) options to not be viewed as a chronological progression of the representation of the language throughout time; instead, they should be viewed as all part of one representation, with no preference or hierarchy. Each representation has its place in history and within the community, and therefore, they should all be presented equally. Additionally, the inclusion of less-known, specific scripts for each language could prompt Indigenous users to discover more about the script itself. The inclusion of perhaps a seldomly used written form is intentional, and can be viewed as a prototype, which when presented to Indigenous community members, could prove useful and credible. Figures 3-4 display the various possibilities for constellation names in Unity.

Below, the possible font styles used in the morphable labels are depicted:



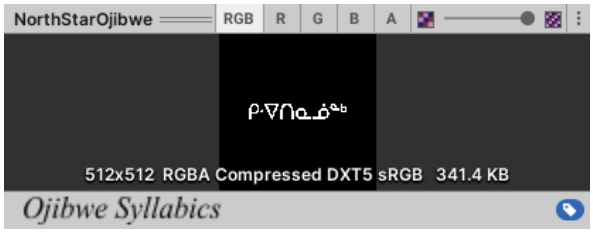



Figure 3: Name outputs for D/L/Nakota constellation “Thunderbird” (Wakinyan) implemented in Unity

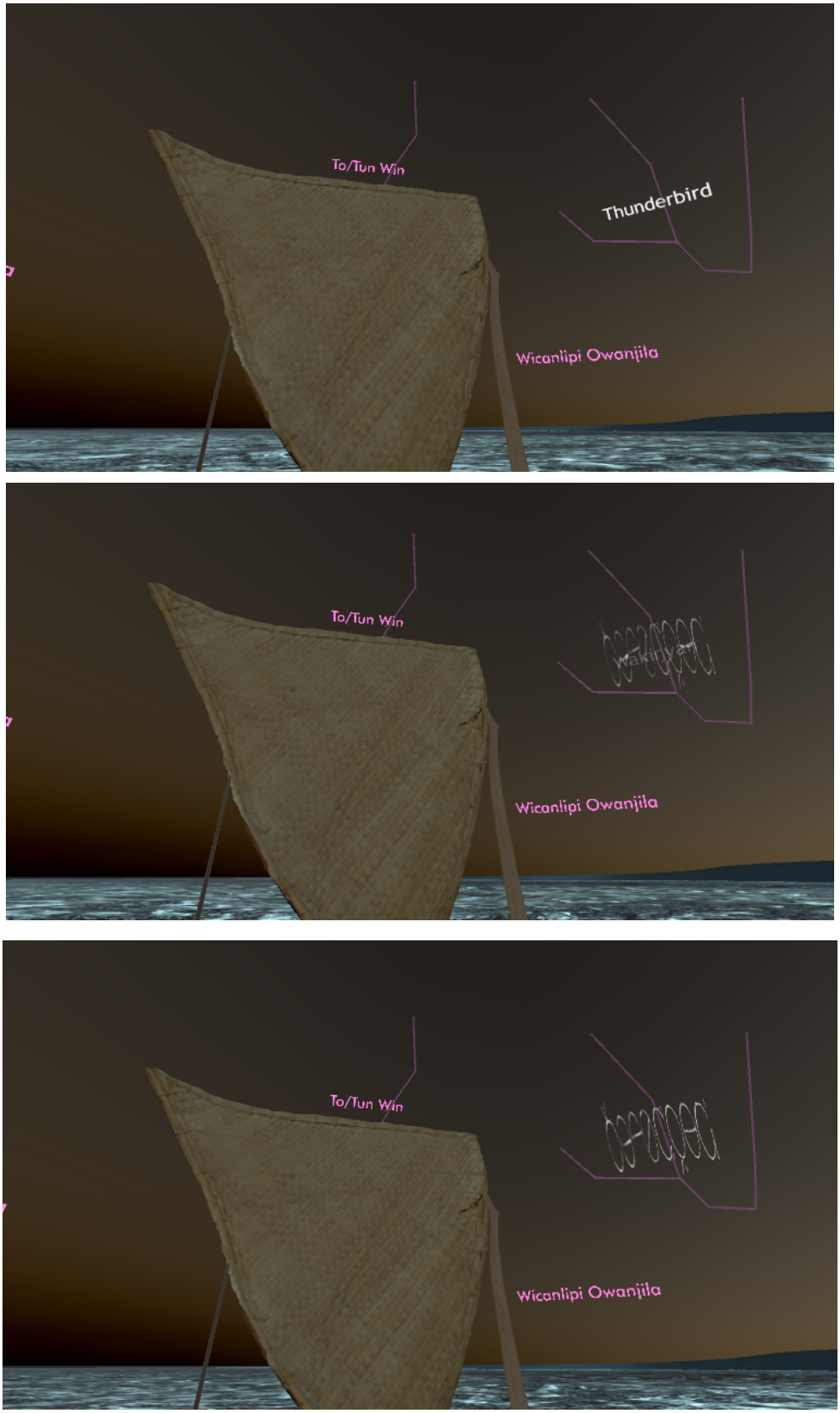
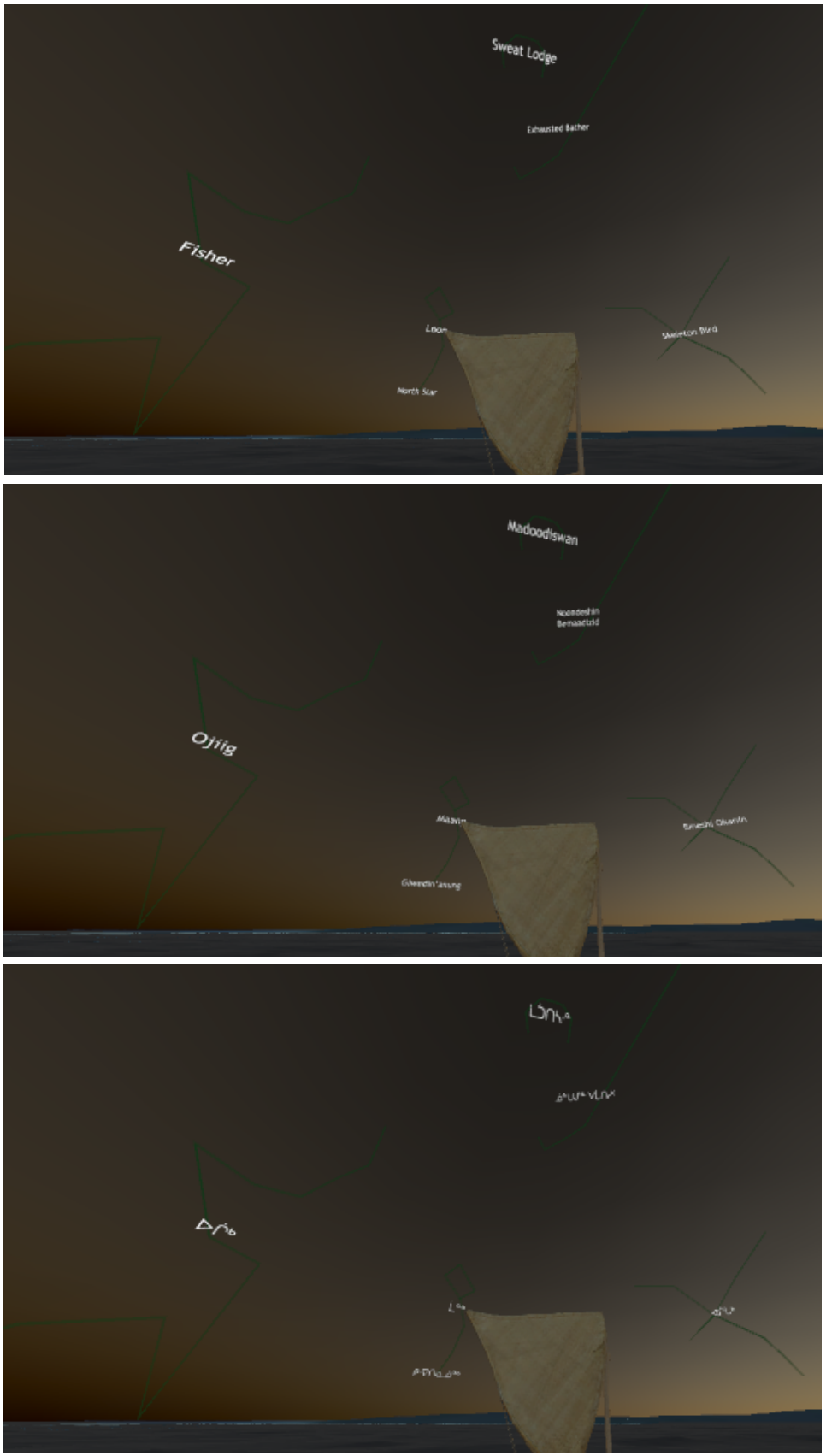


Figure 4: Name outputs for Ojibwe constellation “Fisher” (Ojiig) implemented in Unity



*4.2 Feedback from Indigenous Futures Project Collaborators*

The design critique session led to several interesting insights. Firstly, the researchers reaffirmed the importance of the type of trans-Indigenous exchange this system makes possible. Although the project is just beginning to explore this, we believe the virtual platform could provide an engaging trans-Indigenous experience, in which Indigenous people from different parts of the world can share their traditions. Additionally, the researchers seemed to prefer Canadian Aborignal Syllabic representation over Great Lakes Algonquian Syllabics, simply for its broader and more current use. There was additional excitement about the potential for including D/L/Nakota language. Exploring the visual representation of language is a relatively novel concept, and the team thought utilizing Leroy Curley's symbolic alphabet is likely to be both an applicable and appropriate use of implementing a Dakotah script. With regard to the Micronesian constellations, the written representation of language was viewed as less important, primarily because it's a spoken language. However, the process of critiquing these prototypes from a visual standpoint caused the researchers to reflect on the importance of other aspects of the Micronesian "visual language". For example, the tradition of tattoos in Micronesian culture is one representation of written language. With further research, perhaps there is a way to incorporate this into the current font styles, or perhaps another styling altogether. Most importantly, the researchers emphasized that there is no one "correct" representation of this type of language. The morphing visual helps to convey this; in some sense the "correct" representation is the one that opens the door to a conversation about the histories of the people and language itself. In fact, part of that history is the change in language and its representation over time. Fading in and out between the three types of writing (English, double-vowel/marked, syllabics/symbols) was viewed as the most effective design choice out of the alternatives I prototyped.

**5 Discussion and Future Work**

*5.1 Morphable Labels*

One of the most interesting results of the project is the concept of morphable labels, or more generally, morphable text. Displaying this continual fading and morphing between writing styles carries an

implication that there is no beginning or end to these languages, and even though historically, there is a timeline for each system, in practical use, the timeline is not important to understanding the language. Whether you are Indigenous and don't speak the language at all, speak and read it using English letters, or speak and read using syllabic systems, the experience is made available to various levels of prior experience with the language. Furthermore, the use of the syllabic or symbol system in our rendering could spark curiosity within Indigenous users. An individual could look up to the simulated sky, see syllabic writing, and having not understood what it said, become intrigued to learn more about the system. Perhaps they could come to the decision that the syllabic system is helpful for their learning of the language, and therefore, choose to learn it and utilize it in their daily life. This is the overall goal of this portion of the Indigenous Futures project; the constellation maps for various Indigenous groups, along with written representations of their names, can be used as a language revitalization tool. Even if it's not the syllabic system that intrigues users, the double-vowel or marked representation is equally as intriguing for a new language learner. Either way, this application initiates the conversation about Indigenous language and its use, as well as the history of the language itself and previous attempts to either promote or restrict its use.

*5.2 The Role of Audio*

For a majority of the project, the language aspect has primarily been focused on the *written* use of language, since this is the best and most common way to represent language *visually*. However, there is an entirely different approach to language that is equally as important; *speech*. With this circumstance in mind, it would be beneficial to include some sort of spoken or audio component to the simulation. Perhaps, when the user looks up at the sky and focuses on one constellation in particular, or clicks on the constellation to learn more, they hear the name of the constellation pronounced by a native speaker of the language. This could actually be *more* relatable to the Indigenous person who doesn't speak the language, since maybe they have heard similar sounds or even similar words, being spoken within their family or community. This auditory aspect of languages like Ojibwe and D/L/Nakota has remained vital to the

continuation of the languages' use, and could be helpful to users of this system. This however, raises another question; should written language be represented at all in this program? This is a valid question. Writing has only been around for 5,000-6,000 years, far shorter than how long humans have been capable of verbal communication (around 50,000-150,000 years ago) (Clayton, 2019). It is apparent that writing is a much more modern tool, created to facilitate communication more effectively across geographical areas, as well as for historical documentation. By this logic, a language is no lesser simply because it doesn't have a writing system; more than half of the world's languages have no written form (Swarthmore, 2007). However, in the case of our virtual sky map, this may not be a justification for purely auditory language use. Ojibwe and D/L/Nakota are still taught using *a* writing system, just not one specifically designed for the language. Language education utilizes both writing and speaking components, as both are valid methods of communication. In this vain, the best option may be to make use of both types of language representation. For example, as you look up to the sky, you could zoom in on a constellation and see the morphing and fading names, while also hearing a native speaker say the word or phrase, so that you can now associate certain portions of the writing to the sounds you heard.

*5.3 Standards for Indigenous Language in Computing*

This project has shown the effectiveness of introducing Indigenous text in graphics but not in a standard character set. In Section 2.2, we address the potential for introducing a script into the Unicode standard. However, there are certain drawbacks to a Unicode script that must be considered. For example, many scripts that could be implemented into Unicode were introduced in the late 18th century to North American Indigenous groups were taught and implemented by white, European American scholars. In a period where Indigenous culture was being quite literally eradicated at an alarming rate, and the push for Americanization of Indigenous groups was actual law, it is important to acknowledge that this "tool" introduced to help Indigenous populations more effectively communicate with each other as well as external communities carries overtones of Americanization and cultural suppression. Similar to how the Indigenous Californios in present-day California and the Hopi and Pueblo peoples of the American

southwest were “civilized” by Spanish Catholic missions, the United States has its own dark history of cultural erasure and forced assimilation (NPS, 2020). Another apparent drawback is the potential for a loss of authenticity. Of the few Indigenous languages that have a surviving writing system (since many Indigenous languages exist presently as a spoken language only (Swarthmore, 2007)), nearly all are handwritten. Handwriting is incredibly personalized and distinctive to not only an individual, but also to a community. Various communities could have different styles of drawing characters, and a standardized Unicode script could lead to an inauthentic representation of written language. Additionally, it can be difficult to teach language revitalization through text alone. Many Indigenous languages are primarily spoken within their communities and text alone is sometimes not able to convey the entirety of the pronunciation or stress structure. Although text can be useful alongside speaking, for language education, it perhaps is not the most pressing tool for *teaching* second and third generation native speakers. However, writing is very useful for documenting the current state of the language, so that future generations are able to understand the language if there are few speakers left.

With this discussion in mind, the current state of the constellation names is shown in a new light. For example, using Canadian Aboriginal Syllabics in our program does not pose a challenge to the standard; this character set is already included in the current Unicode standard. However, Great Lakes Algonquian Syllabics and the Lakotah Alphabet created by Leroy Curley are *not* included in the standard. This raises the question of whether or not these scripts should be introduced into the standard. Right now, using them in a graphical context is not difficult, since any image can be represented via graphics. However, when it comes to applications like typing or text recognition, or morphological parsing, the graphics approach fails. If these scripts were represented in the Unicode standard, then they would be far easier to use in everyday digital life, like sending emails or updating a Facebook post. Ultimately, the decision to promote these scripts comes from the people using them, and the people they were created for. Indigenous people are, or at the very least should be, the only people who can make the decision to promote a certain aspect of their native language. Viewing the constellation names through an experimental lens, the prototypes

developed in this project make it possible to start the conversation to explore whether the use of these scripts was useful and effective. If the communities decide language inclusion in digital case studies like this one is useful, this could be a catalyst to expand other digital uses, which might call for deeper discussion about expanding the Unicode standard. Alternatively, if a similar educational experience can be achieved with Canadian Aboriginal Syllabics instead of Great Lakes Algonquian Syllabics, then Unicode can be employed, and a next step for programmers of Indigneous software might be to expand the use and visibility of this already encoded syllabary.

*5.4 Beyond Text Based Representation*

An additional benefit that the virtual reality experience can offer to us is the ability to move past a text based representation of language and incorporate others methods of visualizing Indigenous traditions. The type of star and sky knowledge that this program displays originated as oral traditions, typically without a textual, or even pictographic representation. VR offers us the ability to incorporate alternative forms of re-learning these traditions. For example, outside of a simulation where users read each star or constllation's name in the sky, navigators often create relations with specific stars that go beyond recognizing their visual shapes or patterns. By having learnt the "feel" and even "scents" of the stars, which can manifest themselves in a variety of other ways, navigators are able to "map" the skies upon the land, the sea, their bodies (for example, through tattoos), as well as through spoken, sung, and danced inscriptions (Diaz, 2021). This project opens the door to push the boundaries of how we represent language and traditions, specifically concerning the stars and constellations. Additionally, this can lead to broader discussion concerning how to accurately represent time in a simulation like this, where the traditions that are being displayed can often span centuries. When oral traditions last for many centuries, it can be helpful to think of them as existing within a cosmic timescale, as opposed to an anthropological timescale. VR offers us the opportunity to display time on the appropriate scale, highlighting how the stars that make up traditional constellations have changed since their ancestors last studied them.

## 6 Conclusion

This project, while advancing the way we represent language digitally, still needs to be further explored. The research conducted opened many doors that lead to a variety of paths that future researchers can choose to explore further. This project should be seen as a design study, a digital prototype used to collect feedback from Indigenous communities, specifically concerning their preference in experiencing and learning language digitally. To partner with communities in this work, we have conducted the design study within the context of trans-Indigenous exchange of star knowledge, where the research team is fortunate to enjoy an existing collaboration with three local Indigneous communities. Although this is a highly specific context and, therefore, the technologies and insights may not generalize to other Indigenous computing applications, we believe several themes are likely to be broadly applicable. First, this work reaffirms the potential of custom graphical computing tools for trans-Indigenous exchange. Second, it highlights the challenges of appropriately addressing data sovereignty and multiplicity (i.e., conveying/representing multiple simultaneous perspectives or truths); both of these themes remain major challenges in computing, for the use of language specifically, as well as in general.

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